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An investigation into the energy performance gap between the predicted and measured output of photovoltaic systems using dynamic simulation modelling software—a case study

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Abstract

The use of solar energy can help reduce CO₂ emissions and dependency on fossil fuels, and using Solar Photovoltaic (PV) systems to generate electricity is a popular route to decarbonisation in the UK. To help achieve the targets set out in the Climate Change Act, building service consultants often use EDSL Tas, a dynamic modelling software, to simulate PV systems and integrate the energy output results into the overall energy performance of a building. There is, however, a clear performance gap between the measured and predicted energy output. There are many causes for the potential deviation of results, although the most influential in relation to energy performance is the use of weather data, future climate change, adverse weather conditions and environmental factors affecting the PV array. The results through a case study indicated an 8.6% higher measured energy output from the installed PV system although the performance gap has little detrimental effect regarding achieving Building Regulation compliance, but could lead to the unreasonable design of the PV system and inappropriate use of capital investment. Further simulation using projected future weather data from several different climate change scenarios was undertaken. 2020, 2050 and 2080 with low, medium and high emission scenarios indicated that the PV array would increase energy output by up to 5% by 2080 compared with using current weather data, indicating a rise in PV energy output in relation to increased CO₂ emissions. This is due to a projected reduction in cloud cover and increased downward shortwave radiation.

Keywords: photovoltaics; energy performance; climate change; dynamics modelling

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1 INTRODUCTION

The implementation of an environmentally sustainable energy source is important to the reduction of both CO₂ emissions and the dependency on fossil fuels. The use of solar energy is one of the popular options, among which using photovoltaic (PV) modules to generate electricity is

very promising especially in the contribution towards a building's energy performance.

The Climate Change Act has set targets for the reduction of UK emissions by at least 80% by 2050 relative to 1990 [1]. To contribute to achieving this target, Part L of the Building Regulations 2013 stated that a building must achieve the

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approved minimum energy performance requirements to meet the target CO₂ emission rate (TER). It also stated that this can be calculated using an approved methodology, one of which is a Simplified Building Energy Model (SBEM) [2].

SBEM is a software tool developed by the Building Research Establishment (BRE) that provides an analysis of a building's energy consumption. SBEM is used for non-domestic buildings in support of the National Calculation Methodology (NCM), the Energy Performance of Buildings Directive (EPBD) and the Green Deal [3]. EDSL Tas software is a dynamic modelling software that is compliant with the approved national calculation methodology (SBEM version 5.2.g). In more recent years, designers have had the facility to simulate PV systems using dynamic modelling software and integrate the energy output results into the overall energy performance of a building. EDSL Tas allows designers to perform complex design simulations and analyse energy output. Alternative dynamic simulation packages such as Bentley's Hevacomp software do not facilitate the integration of PV modelling and simulation. Due to more recent developments in EDSL Tas for the integration of PV modelling it is important to further understand if performance issues exist.

As part of the design process, many designers assess the feasibility of integrating low or zero carbon (LZC) technologies into buildings to reduce CO₂ emissions. Due to the high CO₂ emissions factor from grid supplied electricity, PV can have one of the largest impacts on the building energy rating (BER) and therefore, is a popular technology integrated by design engineers.

The UK Government offers a Feed-in Tariff Scheme (FIT) which encourages the installation of renewable energy technologies and provides an incentive for end users. In terms of current usage, as of the end of January 2017, the Department of Energy and Climate Change estimated overall UK solar PV capacity stood at 11 642 MW across 904 089 installations, seeing 18% increase over 12 months [4].

To access the viability for installation, PV modules/panels can be modelled to ascertain the energy yield and subsequent CO₂ emission reduction, financial and energy payback. Previous investigations into the validation of PV modelling software against controlled experimental conditions recorded up to a 10% difference between results and it is stated that this may be a greater concern for the UK where lower angles of incidence are more prominent during the winter period [5]. Previous studies by Mondola *et al.* [6] and Perlman *et al.* [7] into simulation accuracy also had identified issues with the reliability of results. Further, Ransome [8] compared algorithms and assumptions against logged data. The report concluded that although simulation programs used the best available data, many inaccuracies were found in unknowns due to weather data, dirt and shading losses.

There is, therefore, a need for further investigation into the relationship between the energy performance gap between predicted PV output by using EDSL Tas software and actual measured output through a case study.

2 METHODOLOGY

2.1 Location—Poole Methodist Church

Poole Methodist Church (Post Code: BH15 1DF) (Figure 1) was selected to conduct a comparative study investigating the performance gap of PV simulation predictions against the actual measured results of an installed system. The original church construction has stood since 1880 with a new extension constructed in 2015. The church is in Poole, Dorset and is one of the tallest buildings in the surrounding area. The PV installation is sited on the new extension to the building (Figure 2).

The installed PV modules, LG300N1C-B3, were manufactured by LG Electronics Inc. A total number of 52 modules were installed on the building on an 'A frame' bracket system, with the modules split evenly into two groups facing southeast and northwest. The modules were set at an inclination of 10°



Figure 1. Poole Methodist Church front.



Figure 2. PV installation.

on the frame. The DC cabling penetrated the roof and was routed internally to a ventilated plant room, in which an inverter with the facility for remote access to the system's operational data was located.

The original calculation performed in PVSol was also obtained to further analyse the accuracy of PV performance against the simulation model in EDSL Tas.

2.2 Simulation model

The simulation model was constructed using EDSL Tas software. The building was first accurately simulated according to the detailed architectural plans, then the PV modules were integrated into the building model. The software is not specifically designed for PV simulation, therefore, is reliant on the user creating a surface that replicates a PV module and that can accept an irradiance when simulated.

The PV module dimension was taken from the datasheet, using the cell dimensions in lieu of the overall panel dimensions to discount the frame of the module. The modules were placed in the location installed on site and set at an inclination of 10° in line with the installation. 26No. modules were orientated on 295° (Northwest) and the remaining 26No. at 115° (Southeast). Figure 3 shows the simulation model. Other parameters were input manually as below:

- the characteristics of the $I-V$ curve of LG300N1C-B3 modules (from the manufacturer);
- wiring loss of 0.91% as calculated from the original specialist designer software (PVSol);
- solar reflection loss of 6.65% as calculated in PVSol;
- dirt loss of 2% considering that the church implements a clearing regime regularly [9];
- the inverter efficiency of 98% provided by the manufacturer; and
- module degradation of 2% as recommended by the manufacturer.

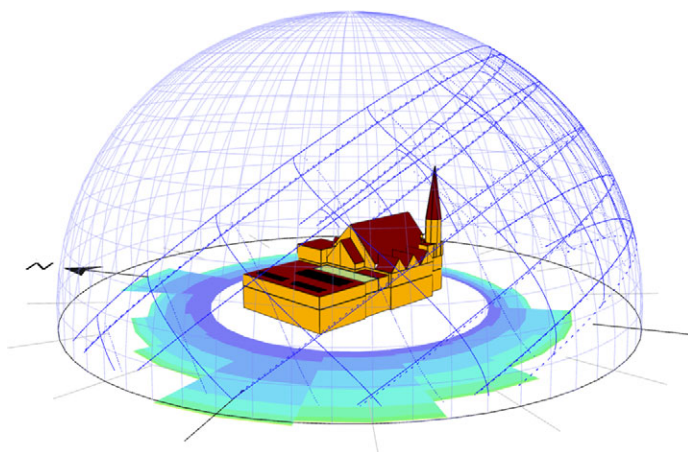


Figure 3. EDSL Tas PV simulation model.

The weather data used was from the CIBSE weather files. To obtain the correct weather data for the area, CIBSE were contacted and the weather file, Test Reference Year (TRY) for Southampton (nearest city to the church for weather data purpose) was purchased. The model was simulated using the updated solar irradiance data from the Southampton weather file which used the average months selected from 1984 to 2013 [10]. To further understand how weather data affects the PV modules' output and how this may vary with climate change projections, simulations have been carried out under 2020, 2050 and 2080 with low, medium and high emission scenarios, using the identical EDSL Tas PV model.

3 RESULTS AND DISCUSSIONS

Figure 4 shows the comparison between the predicted PV energy output using EDSL Tas and the actual site measured results over a 12-month period. It indicates that the PV modules' actual operational data exceeded the predicted results. There appears to be a change in trend in June where the measured output dropped significantly below the predicted. The UK met office reported an often-cloudy month which would reduce the downward shortwave radiation received by the PV modules, therefore, reducing the actual energy output [11].

To assist in the further analysis of these results, the existing PVSol simulation results were brought forward, i.e. 13 338.0 kWh a year with the Poole AS weather data 1986–2005; while annual predicted energy yield from EDSL Tas software was 13 011.6 kWh with CIBSE weather data 1984–2013 and measured figure was 14 235.0 kWh a year. It is clear that both PV prediction software fell short of the actual energy output of the PV system. There is a performance gap of 8.6% between the EDSL Tas simulation and the measured output, and a gap of 6.3% between PVSol and the actual output. There are many different contributing factors, as below, that may have caused a deviation in results.

3.1 Software functionality

The EDSL Tas dynamic modelling software has many limitations when simulating PV systems. As the software's primary

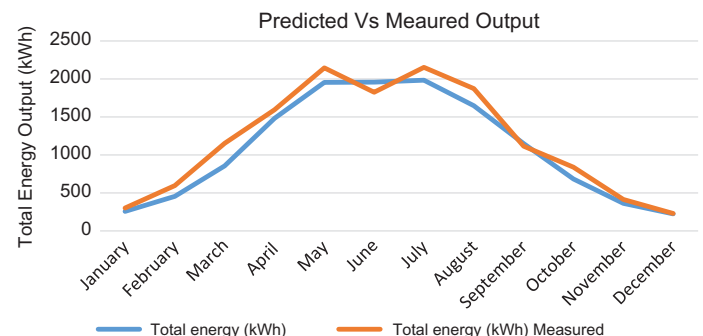


Figure 4. Predicted vs measured PV energy output.

use is not the modelling of PV systems, elements of data entry do not appear to be part of the overall system calculation and create unreliability in results.

The building model and PV modules can be inserted in the correct orientation and inclination. The software allows to input data based on power output dependent on irradiance, shading, soiling, wiring losses, aging reduction, solar reflectance and inverter efficiency.

The energy output is directly affected by the ambient temperature. The module details are user created although there is no function to enter data that takes the specific module efficiency related to ambient temperature, thus not providing accurate predicted outputs which are ambient temperature dependent.

The PV system wiring cannot be inserted into EDSL Tas and therefore, without alternative software performing cable calculations or manually performing calculations any contributing wiring and diode losses cannot be accurately ascertained using the dynamic model. The percentage loss for this model was collected from the alternative PV simulation software.

When contacting the manufacturer in relation to solar reflectance they stated that this was negligible although when the modules were used in the original PV modelling software PVSol, the parameters attached to the module found there was a 6.65% reduction in output due to reflection. This function is another user input item which can prove difficult to obtain from the manufacturer.

The output of the panel is dependent on the irradiance received. This must be entered manually within the software from the output presented on the *I-V* curve characteristic graph. This was not easily ascertained from the manufacturer, and in some cases, may not be readily available requiring manual interpretation from the graph. This method again increases the chance of user error or misinformation.

To summarise, due to the amount of user created information, there is the increased chance of incorrect data entry, potentially affecting the reliability of the energy output calculation.

3.2 Climate conditions

(a) Current weather data

The dynamic modelling software EDSL Tas uses CIBSE weather data, historically used for building performance analysis tools. CIBSE licences data from Meteorological office weather stations across 14 sites in the UK. The weather variable required for the solar irradiance data is a TRY file. This type of weather file is composed of 12 separate months of data, each chosen from a series of historic collated data. This type of file is required for compliance with Part L of the UK Building Regulations [10].

Because of climate change, the weather data may quickly become outdated and with the effects of global warming and rising temperatures, irradiance levels, and corresponding energy output could be greatly affected. Two factors that directly affect the PV output are global horizontal irradiance and ambient temperature.

The model has used the most recent available weather data sets to estimate energy yield. These are only guidance figures based on previous weather trends and do not account present or future weather predictions.

It was reported [12] that future climate projections in 2080 indicate in Southern England an ambient temperature rise of up to 6.8°C average and a maximum of 9.5°C, which could reduce overall efficiencies of PV arrays based on specific module temperature. It was also found that the summer average cloud amount in Southern England decreased up to 33% which indicated up to an extra +45 W/m² downward shortwave radiation, which could provide differing results than those modelled using current weather data.

To investigate the future system's energy output the simulation was also modelled based on the current CIBSE (1984–2013) weather data to assess the prediction in terms of energy output, in the Year 25, integrating panel degradation as stated before.

Figure 5 shows that the output expected in the Year 25 ~18% less than the initial install, aging at a rate of 0.7% each year after the Year 1. Reviewing the expectations of climate changes, the weather data shows for a potential increase in energy output in future years. Using existing weather files for future energy predictions including financial viability may prove inaccurate. Further studies have been carried out to assess this impact.

(b) Future weather data

UK Climate Projections give different atmospheric variables during several time periods and under different emission scenarios, with the main variables being mean temperature and cloud cover affecting PV production.

To establish the effects of climate change published by UK Climate Change Projections, the initial Year 1 simulation has been calculated using emissions scenarios for 2020, 2050 and 2080. The comparison has been made between the use of existing weather data and future scenarios, and if a change in high or low emissions probability will change the outcome of PV predictions.

The climate scenarios are available from CIBSE in TRY format and are presented in Table 1 as follows:

The scenario of probability represents that of each possible climate outcome. The percentile is the probability of occurrence, for

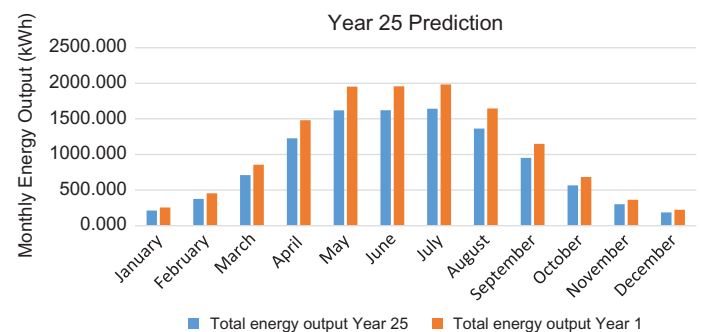


Figure 5. Year 25 PV prediction.

example at the 10th it is very unlikely to be less than, the 50th represents central estimates and at the 90th it is very unlikely to be greater than [13].

Figures 6–8 show that using scenarios from 2020, 2050 and 2080 (low, medium and high emission scenarios), EDSL Tas simulation predicted a rise in the energy output of the PV simulation model. It also indicates that a lower output was predicted using the 2020 weather projections against current weather data sets.

Using 2020 projected weather data, the results indicate a decrease in energy performance against current TRY weather files (1984–2013). This could be assigned to increased cloud cover projections reducing the downward shortwave radiation, therefore, reducing energy output.

The output from the 2050 and 2080 climate projection indicates an increase in energy output. It is because that reduced

cloud cover in the South of England in 2050 and 2080 will increase shortwave radiation, leading to the essential increase of the irradiance received by the modules [14].

Figures 6–8 also show that dependent on the emissions scenario, there is an impact on the output of the PV modules. In each emissions scenario at 10, 50 and 90% percentile, the PV modules' output shows a deviation of up to a maximum of 5% from current weather data to the 2080 future high emissions scenario. Dependent on the development of climate change and how mitigation is action is taken, PV prediction will continue to encounter performance gap issues subject to the weather data used.

Between 2016 and 2080 the results show a steady rise in PV modules' output in the system at Poole Methodist Church and an aspect of the current global emissions, relating to that of over the past few decades have already committed future change and cannot be changed or avoided in a practical sense due to inertia of the climate system [14]. The 2050 and 2080 projected climate scenarios are closer to the actual yield of the installed PV modules and as the global emissions have already been committed to future climate change it may be more beneficial to select future weather data to estimate PV modules' energy output through dynamic simulation modelling.

Opportunities can be gained from the increased global warming although generally, this has a negative effect on the natural environment. Due to the time lag when dealing with the effects of climate change it is likely that we will be locked into this change for several years [15].

The results indicate the PV systems could potentially benefit from the change in climate conditions as we progress to 2080. Where temperatures are expected to rise, this will have a negative effect in extreme summer conditions as the PV module efficiencies reduce, which is not considered in the EDSL Tas Model. Overall, the trend predicts that change in climate will affect the output of PV. When estimating PV modules' output, the results show that PV simulation models use the future weather projections to more accurately analyse a system that will account for climate change over the lifetime of the installation. Also, depending on the changes to the way global warming is addressed, radical changes will affect total energy production

Table 1. Future climate scenarios.

Year	Emission scenario	Percentile		
2020	High emission scenario	10th	50th	90th
2050	Medium emission scenario	10th	50th	90th
	High emission scenario	10th	50th	90th
2080	Low emission scenario	10th	50th	90th
	Medium emission scenario	10th	50th	90th
	High emission scenario	10th	50th	90th

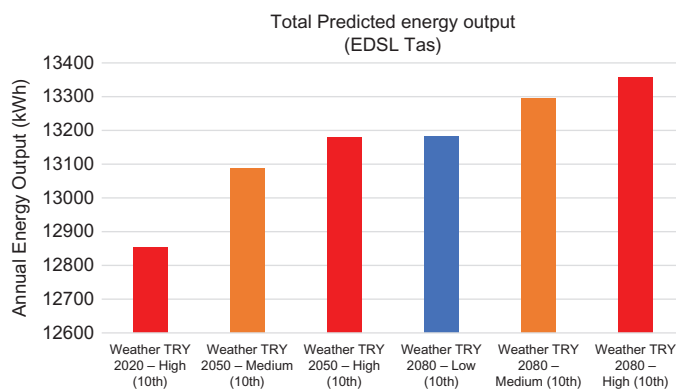


Figure 6. Predictions using future weather scenarios 10th percentile.

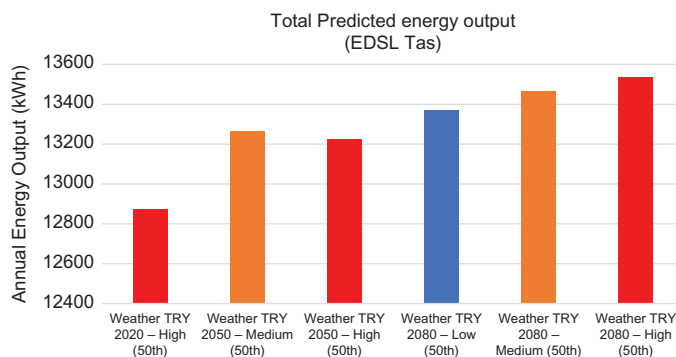


Figure 7. Predictions using future weather scenarios 50th percentile.

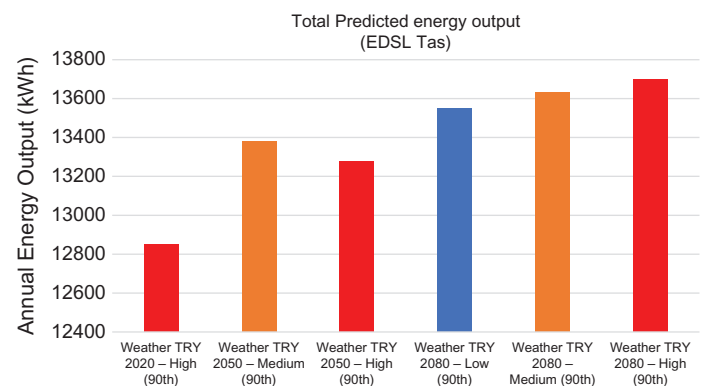


Figure 8. Predictions using future weather scenarios 90th percentile.

from PV modules. A difference of 3.8% in relation to energy output is indicated between the best and worst case scenarios in 2080.

Temperature can have an impact on the efficiency of PV modules. There is a clear decrease in efficiency when the ambient temperature increases [16]. In this case study, the annual mean ambient temperature in the South West of England has risen by 1.21°C since 1961 [15]. Due to the rise in temperatures, it could potentially prove beneficial for greater accuracy in prediction, using more recent average weather data, to give more recent temperature reliability and less variance in results.

The calculation in PVSol will be affected by the temperature accuracy. The parameters of temperatures related to efficiencies are attached to the manufacturer's information when the module is inserted from the database, although this is not an element that is specific to the module in the dynamic modelling software. The prediction in PVSol calculation uses local weather files which differ from the EDSL Tas, Southampton, CIBSE weather files. The Poole AS (1986–2005) are used and the output of the PV will directly correlate with the temperature. The weather data used from the local data source will show more specific information related to the direct area and will give a more accurate yield assumption. Although a direct comparison cannot be made between the two results, it highlights that there are varying types of calculation in the industry and shows how they will present differing energy outputs related to weather data.

The change in the mean temperatures is also highlighted in the update of the CIBSE TRY weather data sets (from 1984 to 2013), i.e. there has been a drop in mean temperature in Southampton, however, some other UK locations shown a rise in temperature. This highlights that there are many differing trends depending on location and a more specific weather station location will produce more accurate predictions.

3.3 Shading and soiling

Shading will vary depending on the time of year, with the amount of shading affected by proximity to nearby surrounding obstructions. Poole Methodist Church was situated in an area of 'low rise' buildings causing limited effects due to shading although the front of the existing church was situated to the south and has caused the most impact due to shading with the height of the main hall and the spire. This was all considered in the dynamic building model providing an accurate representation of the shading effects. The shading factor calculation is only correct for the initial prediction, although long term, buildings or other objects that are erected in close proximity could present negative effects on the system related to the energy output.

Soiling of PV modules has a great influence on the power loss through the accumulation of snow, dirt, dust and any other type of particle. The soiling of the installation was taken at 2% using the dynamic modelling software. The church had cleaned the PV modules on inspection, when they appeared to

have accumulated dust, within the first year. It can prove very difficult to estimate the accumulation of dust and another soiling. The accumulation is dependent on several factors including inclination of the PV modules, precipitation in the area and any cleaning regimes. The area is close to the coast and bird droppings are a very apparent problem, with dropping usually not removed by precipitation. RezaMaghami [17] in a review of PV soiling stated that pollution causes a variation on PV output in different seasons and different inclinations of the array, showing winter has a higher impact on output due to air pollution. A frequent cleaning regime will help provide maximum energy yield maximising financial returns for the owner.

It is also worth mentioning that a greater performance in actual measured output would have an impact on the economics of PV systems. Decisions on the viability to install a PV system largely depends on early prediction models indicating energy yield and financial returns. Although the dynamic model may not illustrate financial predictions, early stage feasibility proposals may be recommended using the dynamic modelling energy outputs. In terms of payback, the owner would benefit long terms if there were a continuation of greater actual measured readings than the initial simulation prediction. If a specific output is required as part of an SBEM calculation in the dynamic model for Part L Building Regulation compliance, an underestimated prediction may give the assumption that more PV is required than necessary, creating a greater capital investment than required possibly affecting the initial decision to invest in the system.

In addition, as part of the process to show compliance, integrated PV system can be used to compensate for other building inefficiencies, which means greater responsibility for accuracy of predictions to ensure compliance with Part L of the Building Regulations 2013. The simulated prediction for Poole Methodist Church shows underestimation, therefore, the measured system provides greater CO₂ reduction contributions and would have no detrimental effect to cause non-compliance through the estimation.

4 CONCLUSIONS

It has been found that a performance gap exists between the predicted and measured output in PV systems using dynamic simulation modelling software, EDSL Tas. The results indicate that the software underestimated the energy output prediction. This underestimation can be associated with many factors throughout the calculation stage, with the main contributing elements being the weather data used to calculate the predicted output.

To summarise the findings of the results:

- (1) A performance gap of 8.6% was found between the predicted and measured output of PV systems using dynamic simulation modelling software, EDSL Tas.

- (2) A performance gap of 6.3% was found between the predicted and measured output of PV system compared with the original specialist calculation using PVSol.
- (3) An increase of 5% was found between the predicted output of PV systems using future weather projections for 2080 high emissions scenario and current weather data (1984–2013) in EDSL Tas.
- (4) An increase of 3.8% was found between the predicted output of PV systems using future weather data in the 2080 best and worst climate change scenarios in EDSL Tas.

CONFLICTS OF INTEREST STATEMENT

None declared.

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